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BASEFLOW ACCRETIONS, LOW FLOWS, AND WATER QUALITY IN THE FOX RIVER IN KANE COUNTY, ILLINOIS: PRESENT CONDITIONS AND PROJECTIONS BASED ON PUBLIC WATER SUPPLY TRENDS

by

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and
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INTRODUCTION

The Fox River flows from north to south through the eastern half of Kane County, Illinois. In 1980 over 90% of the county's 278,405 inhabitants resided in communities bordering the Fox River. Kane County has the fifth-highest county population and the fourth-highest county population density in Illinois. Public water supplies are obtained almost exclusively from ground-water resources. In 1984, aquifers in Cambrian-Ordovician bedrock (deep sandstone aquifer) supplied 76% and shallow aquifers in sand and gravel and Silurian dolomite supplied 24% of the ground water used by the county. The city of Elgin is the only municipality utilizing the Fox River for potable water.

The deep sandstone aquifer has been overdeveloped throughout most of northeastern Illinois. In Kane County water levels declined at an average rate of 11 ft per year during the period 1961 to 1975 and 7 ft per year during the period 1975 to 1980 (Sasman et al., 1982). Declining water levels are motivating communities currently using the sandstone aquifer to develop other water resources. Elgin began operation of its river water treatment plant in 1983 to supplement ground-water withdrawals. Prior to 1983 Elgin obtained all of its water from wells in the deep sandstone aquifer.

The alternative water supply sources in the region in addition to the Fox River are shallow aquifers in glacial deposits of sand and gravel and, to a lesser extent, shallow dolomite aquifers in some parts of the county. Some shallow aquifers in sand and gravel or dolomite may be in hydraulic connection with the Fox River. Large withdrawals from these shallow aquifers may influence river flows by reducing baseflow accretions to the Fox River. In cases of very large withdrawals, the drawdown of the water table may be sufficient to cause a recharge of the aquifer from the river, reducing river flow.

Water withdrawn for public supply from ground-water resources is presently discharged to the Fox River via the wastewater treatment plants serving the riverside communities. Water which is obtained from the sandstone aquifer or shallow aquifers not in hydraulic connection with the river, and which is discharged to the Fox River, increases the river flow. This increase will be lessened as communities start switching from these independent sources to surface water or aquifers in connection with the river. Alternatively, withdrawals from shallow aquifers not in connection with the river will continue to increase river flow.

The Fox River receives wastewater from all the communities situated along its banks in Kane County. The total average daily effluent volume discharged to the Fox River between Algonquin and Aurora was 56 cfs (cubic feet per second) in 1984. In the past, river flows increased with increasing effluent discharges because the greater portion of the effluents originated from an independent source. If river water is used for supply, effluent discharge will be a return of the water withdrawn (less losses). As demands and hence effluents increase, a greater portion of the river water will be treated wastewater, which may significantly affect water quality.

As part of an evaluation of the total water resource in Kane County, the potential for interaction between shallow aquifers and the river was investigated, as well as the consequences of communities switching to surface water for public supply. The specific objectives of this study were as follows:

1. Prepare a descriptive history identifying pertinent physiographic characteristics, developments, and improvements which may have affected river flows; population trends; water supply systems; sources of supply and water usage; and wastewater treatment plants and effluent volumes. Make projections of future water demand and wastewater loads from historical trends.
2. Investigate the potential interaction of shallow aquifers with the Fox River through a field study of variations in baseflow accretions.
3. Determine the current status of river water quality in terms of general use and potable water supply standards, and in general assess the potential impact of switching water supply sources.
4. Develop low-flow statistics for the Fox River for the present conditions and for various water withdrawal scenarios under present conditions and anticipated future demand. Compare low-flow statistics

to evaluate changes in the river low-flow regime created by some communities switching to the river (or aquifers in hydraulic connection) for supply. Assess possible limits to water withdrawals imposed by compliance with minimum dilution ratios for effluent discharges and by consideration of environmental degradation caused by extending low-flow periods.

Acknowledgements

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STUDY AREA

Physical Characteristics of the Fox River Basin

The Fox River rises in Waukesha County, Wisconsin, and enters the state of Illinois at the northern border of McHenry County. At the Wisconsin-Illinois border the Fox River has a drainage area of 870 sq mi. The river continues in a southerly direction, flowing through a series of lakes (called the Fox Chain of Lakes) in McHenry and Lake Counties. It enters Kane County at its northern border with a drainage area upstream of 1402 sq mi and flows southward along the eastern side of Kane County, draining approximately 320 sq mi in Kane and small portions of Cook and DuPage Counties before leaving Kane County at its southern border. The Fox River then flows southwest, joining the Illinois River at Ottawa with a drainage area at its mouth of 2658 sq mi. The basin area includes all or part of Waukesha, Racine, Walworth, and Kenosha Counties in Wisconsin and McHenry, Lake, Cook, Kane, DuPage, Kendall, DeKalb, and LaSalle Counties in Illinois. The study area in Kane County extends from the village of Algonquin at the McHenry-Kane County line downstream to the village of Montgomery at the Kane-Kendall County line.

The uplands of the Fox River basin above Algonquin in Illinois are generally flat with numerous swamps, marshes, and lakes. Downstream of Algonquin the terrain changes significantly: the land becomes more hilly, with bluffs encroaching on the floodplain. The basin is approximately 28 miles wide at the Wisconsin-Illinois border; near Algonquin it is 17 miles wide. It narrows to a minimum width of 10 miles near Geneva, and south of Geneva it begins to widen again.

There are nine major tributaries to the Fox River between Algonquin and Montgomery. The names of the tributaries and their respective drainage areas (Healy, 1979) are given in Table 1.

There are 15 dams on the Fox River, ten of which are located in Kane County. These dams create pools of considerable size and slow the river flow. Many of the original dam structures were erected prior to 1900. Most of the dams have a fixed spillway with no movable structures to artificially control flows. Two dams north of Kane County have movable

Table 1. Major Tributaries in the Study Reach

Tributary	Drainage area (sq mi)
Crystal Creek	27.0
Jelkes Creek	6.8
Tyler Creek	40.4
Poplar Creek	44.5
Brewster Creek	17.5
Norton Creek	11.7
Ferson Creek	54.4
Mill Creek	31.0
Indian Creek	16.7

gates which can be used to control flows: Wilmot Dam at Wilmot, Wisconsin, and McHenry Lock and Dam near McHenry, Illinois.

The Wilmot dam is situated approximately 1 mile north of the Wisconsin-Illinois border. The original dam was erected in 1852 and was a straight overflow structure. The present structure was built in 1942 and has 3 movable gate sections to regulate flow. The purpose of the gates is to maintain specified minimum lake levels in Wisconsin. Thus the gates are designed to control low to normal flows. Typically, mean daily flows from the Fox River into Grass Lake (upstream lake in the Chain of Lakes in Illinois) exceed 50 cfs during dry periods. However, there have been short periods (a few days) of no flow into the Chain of Lakes because of artificial regulation at Wilmot Dam. During periods of high flow, the effect of the gates is drowned out and the dam and gates function as a straight overflow structure.

The McHenry Lock and Dam is located 6.9 miles downstream of the Pistakee Lake outlet in the Chain of Lakes. Prior to 1915, a 6-foot-high steel sheet piling structure was erected. This structure was replaced by the present 6.5-foot-high dam in 1939. The dam has a fixed spillway crest and a low flow section with 5 movable gates. During low and normal flows the gated section is used to maintain lake levels in the Chain of Lakes. Lake levels are very sensitive to changes in gate openings when flow is low. The dam controls outflows from the upper 1250 sq mi of the watershed, has a significant impact on lake levels, and influences downstream low flows. Current operational policy calls for maintaining at least a 0.10-foot flow over the fixed spillway, approximately 36 cfs during the months of June through November. Lowest flows most often occur in August or September. During dry periods the gates are closed provided the pool stage can be kept above the crest elevation. The gates may be opened up to 0.05 ft, allowing up to 43 cfs discharge, if the pool stage falls below the dam crest elevation. However, the lowest inflows the Chain of Lakes has ever experienced in August would provide for maximum evaporation plus some flow over the spillway with the gates closed (William Rice, IDOT, personal communication, 1985).

The daily flow data collected at the USGS gage at Algonquin were reviewed to determine if changes in operational policy during the more than 40 years of the McHenry Dam's existence have affected trends in low flows downstream. The Algonquin gage is approximately 16 miles downstream of the McHenry Dam, and a continuous record of daily flows from 1916 to 1983 is available. The daily flow data were adjusted for increases in effluent inflows over the years. Plots of 7-day low flows versus return interval for the period prior to the gated dam construction (1916-1939) and the period after the present dam was built (1941-1982) have comparable trends for high return intervals (e.g., 7-day 10-year low flow). Gate operation does not appear to have affected trends in extreme low-flow periods. Seven-day low flows with lower return intervals (e.g., 2 years) tend to have been higher since construction of the gated dam. This is partly attributable to generally wetter conditions and high flows for the region from 1970 to 1982. Flows recorded at the USGS Wilmot gage upstream of the Wilmot dam also indicate generally higher flows for 1970 through 1983 than for 1939 to 1969. The Algonquin gage provides the longest continuous flow data for the Fox River. This record begins after construction of the original Wilmot, McHenry, and Algonquin dams. Thus there are no records for totally natural flows in the Fox River.

There are 13 in-channel, fixed spillway dams downstream of the McHenry Dam, 10 of which are located in the study area. The locations and design pool lengths at crest elevation for the dams in Illinois are shown in Table 2.

The pools created by these impoundments increase surface area exposure and thus increase evaporation losses, measurably decreasing low flows. Singh (1983) estimates a loss of 3 cfs per square mile of surface

Table 2. Fox River Dams in Illinois

Location	River mile*	Pool length (mi)	Surface area at crest elevation (acres)
McHenry	98.94	6.8	403
Algonquin	82.61	16.3	849
Carpentersville	78.15	4.5	140
Elgin	71.85	6.3	314
South Elgin	68.18	3.7	192
St. Charles	60.65	5.2	295
Geneva	58.67	2.0	89
Batavia	58.38	1.1	68
South of Batavia	54.9	1.5	74
North Aurora	52.60	2.3	133
Aurora	48.91	1.0	67
South of Aurora	47.90	1.0	48
Yorkville	36.54	2.2	111
Dayton	5.67	4.1	199

*Measured from mouth at Ottawa; mileages differ slightly from USGS reported values

Reference: Ill. Division of Waterways, Dept. of Public Works and Buildings, 1962

area for instream pools on the Fox River during dry periods, typically late August through September. The pools created by the Algonquin and McHenry dams, together with the numerous lakes, swamps, marshes, and sloughs between Wilmot and Algonquin, expose considerable water surface area to evaporation. Evaporation losses in this region during dry periods are comparable in magnitude to the various tributary inflows, ground-water accretions, and effluent inflows (1980 levels) which would contribute to the 7-day 10-year low flow at the Algonquin gage (Singh, 1983). Thus, during very dry periods there is little net increase in flow between Wilmot and Algonquin.

Communities and Industries

There are numerous cities, villages, subdivisions, institutions, and industries situated along the Fox River as it flows through Kane County. This study focuses on those communities which are using or could use the Fox River in Kane County as either a source of water supply or a receptor for wastewater. Several communities in the study area lie partially or completely in adjacent counties, such as Algonquin, which is located for the most part in McHenry County but discharges its wastewater to the Fox River as it passes through Kane County. Similarly, Streamwood is in Cook County but discharges its wastewater to the Fox River via the Elgin Sanitary District facilities. The city limits of Elgin and Montgomery cross county lines. Cities such as Elburn and Sugar Grove in Kane County, although in the Fox River basin, are too far from the main stem of the Fox River to be considered in the study area.

Population

Over 90% of the population of Kane County resides in communities along the Fox River. This population makes up over 95% of the study area population. Thus differences in demographic statistics for Kane County and for the study area will be small, and trends are comparable. Communities served by major public water supply systems within the study area are listed in Table 3 together with their 1980 populations and estimated 1984 populations. The population figures tabulated represent residents within the city limits. City water supply systems also serve some residents outside of the city limits, and many residents near the city have individual private wells. An exact accounting of the population served by a system would require an examination of billing records. In lieu of this, the city populations were checked against the estimates of populations served that were reported to the State Water Survey by the operating facilities, and per capita consumption was calculated and checked for reasonableness. Population estimates used in this study for years after 1980 are based on the State of Illinois Bureau of the Budget (1980) projections for Kane County and the 1980 populations reported by the U.S. Bureau of the Census (1981). Percent increases were calculated from the projected change in total county population and were applied to the total populations of those communities listed in Table 3.

Water Supply

Traditionally, ground water has been the primary source of water supply for public and industrial use in the area. From the early 1900s up to 1983, 100% of the public water supplv was obtained from ground-water resources. In 1983 the City of Elgin began withdrawing water from the Fox River for public use. All other public supplies are still obtained

Table 3. Populations of Communities Within the Study Area

	Population in 1980	1984
Algonquin	5,834	6,318
Aurora	81,293	88,040
Batavia	12,574	13,618
Boulder Hill Sub. (served by Montgomery Water Supply)	9,333	10,108
Carpentersville	23,272	25,204
East Dundee	2,618	2,835
Elgin	63,798	69,093
Geneva	9,881	10,701
Montgomery	3,369	3,649
North Aurora	5,205	5,637
St. Charles	17,492	18,944
Sleepy Hollow (served by West Dundee Water Supply)	2,000	2,166
South Elgin	6,218	6,734
Streamwood	23,456	25,403
Valley View	2,117	2,293
West Dundee	3,551	3,846

exclusively from ground-water sources. Illinois defines public water supplies as "systems or wells that furnish water for drinking or general domestic use in incorporated municipalities, and unincorporated communities where 15 or more separate lots or properties, or 25 persons, are being served, or are intended to be served, at least 60 days per year" (Kirk et al., 1985).

There are three major geologic systems from which ground water is derived in the area: glacial drift deposits of unconsolidated sand and gravel, the Silurian dolomite aquifer, and the Cambrian-Ordovician sandstone aquifer. The glacial drift deposits occur locally along the Fox River and may be in hydraulic connection with the Fox River. The Silurian dolomite aquifer is present throughout northeastern Illinois. In some areas the dolomite directly underlies water-bearing deposits of sand and gravel and there is free exchange of water between the systems. The Cambrian-Ordovician sandstone aquifer system underlies much of northeastern Illinois. This aquifer is confined by layers of impermeable strata and is not in hydraulic connection with the Fox River.

There are 25 public water supply systems operating within the study area. Of these, 14 serve cities and villages with populations greater than 2000, 2 serve institutions, and the remainder serve unincorporated areas. Locations of the public ground-water systems are shown in Figure 1. Elgin's water supply system also serves the village of Sleepy Hollow (since 1982) and Elgin State Hospital (since 1983). Formerly, each operated its own water supply system. The supply systems for St. Charles, Geneva, and Batavia are cross-connected.

The public water supply systems and quantities of water obtained from each source (ground water and surface water) in 1984 are listed in Table 4. The percent of total water obtained from each source is also indicated, as well as total withdrawals for 1984. The quantities tabulated were derived from basic data collected for the Illinois Water Inventory Program (Kirk et al., 1985). The 14 water supply systems primarily serving incorporated areas account for more than 98% of the total water withdrawals for public use in the study area.

The Carpentersville, East Dundee, South Elgin, and Valley View supply systems are served exclusively from shallow, local water-bearing sand and gravel deposits. Part of East Dundee's supply comes from springs connected with sand and gravel. West Dundee and Streamwood derive the majority of their water from wells open to sand and gravel, and Algonquin and St. Charles obtain a substantial portion of their water from these deposits. As shown in Table 4, water-bearing sand and gravel deposits provided 21% of the water supplies for cities and villages in the area. The city of Elgin has two standby wells finished in sand and gravel. Several other shallow wells with depths of 50 to 100 ft, used by Elgin in the past, have been abandoned.

Most of the shallow wells in the area have been used for 30 or more years. The pumpage from sand and gravel aquifers one mile or less from the river is concentrated in the Carpentersville-East Dundee-West Dundee area

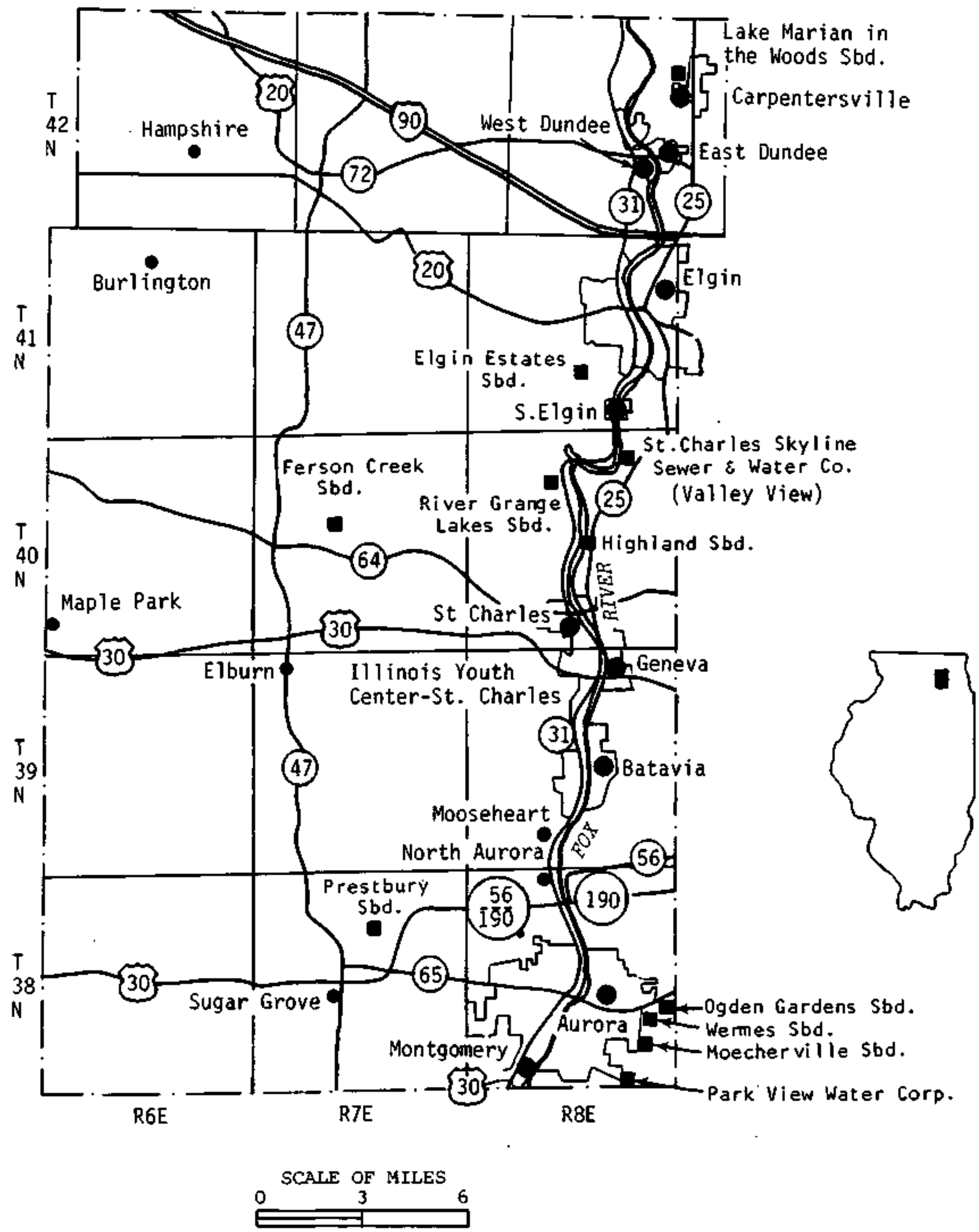

Figure 1. Location of public ground-water supply systems in Kane County (after Woller and Sanderson, 1978; ■ and ● denote subdivisions and municipalities, respectively)

Table 4. 1984 Withdrawals by Public Water Supply Systems

Public water supply systems serving cities and villages	Major Geologic System: Sand or gravel mgd	Sand or gravel % of total	Silurian dolomite mgd	Silurian dolomite % of total	Cambrian-Ordovician mgd	Cambrian-Ordovician % of total	Surface water mgd	Surface water % of total	Total mgd
Algonquin	.36	39	.50	54	.07	07		0	.93
Aurora		0		0	10.46	100		0	10.46
Batavia		0		0	1.54	100		0	1.54
Carpentersville	2.72	100		0		0		0	2.72
East Dundee	0.30	100		0		0		0	.30
Elgin		0		0	5.38	50	5.44	50	10.82
Geneva		0		0	1.83	100		0	1.83
Montgomery		0		0	1.39	100		0	1.39
North Aurora		0		0	0.93	100		0	.93
St. Charles	1.69	46		0	1.99	54		0	3.68
South Elgin	0.73	100		0		0		0	0.73
Streamwood	1.74	73		0	0.66	27		0	2.40
Valley View (St. Charles Skyline Sewer Water Corp.)	.04	100		0		0		0	.04
West Dundee	.47	96		0	.02	04			.49
Total	8.05	21	.50	01	24.27	64	5.44	14	38.26

Table 4. Concluded

Public water supply systems serving unincorporated subs.	Major Geologic System: Sand or gravel mgd	Sand or gravel % of total	Silurian dolomite mgd	Silurian dolomite % of total	Cambrian-Ordovician mgd	Cambrian-Ordovician % of total	Surface water mgd	Surface water % of total	Total mgd
Elgin Estates Sub. (Rollins Sewer & Water Company)		0	.02*	100		0		0	.02
Ferson Creek Sub.	.06	100		0		0		0	.06
Highland Sub.		0	.005	100		0		0	.005
Lake Marion in the Woods Sub.	.03	92	.003	08		0		0	.033
Moecherville Sub.		0	.09	100		0		0	.09
Ogden Gardens Sub.		0	.03	100		0		0	.03
Park View Water Corp.		0	.004	100		0		0	.004
River Grange Lake Sub.	.01	100		0		0		0	.01
Wermes Sub.		0	.01	100		0		0	.01
Total	0.10	38	.16	62	0		0		.26
Institutions									
Illinois Youth Center-St. Charles		0		0	0.,13	100		0	0.13
Mooseheart Home for Children		0		0	0..18	100		0	0.18
Total	0		0		0.,31	100	0		0.31
							GRAND TOTAL		38.8

*1983

and around South Elgin and Valley View. Streamwood's wells are several miles from the river channel.

Population and public water demand in the area has steadily increased over the years. Figure 2 shows a plot of the average daily water use in million gallons per day (mgd) and the population from 1940 to 1984 for the cities and villages listed in Table 3. Projections to the year 2000 are also shown. Historical records of municipal ground-water withdrawals are maintained by the Illinois State Water Survey and were used to develop the plot for the period 1940 to 1979. Beginning in 1978 information on annual withdrawals from individual wells located in Illinois has been collected for the Illinois Water Inventory Program. The basic data collected for the cities and villages in the study area were used to complete the plot of water use for the period 1980 to 1984. U.S. Bureau of the Census (1971, 1981) decennial census data for each city and village were used to develop the population curve.

The water use projections shown in Figure 2 are based on the projections made by Singh and Adams (1980). They developed water use functions on the basis of population, industrial employment, and water use in 1970, from which water demands for individual communities were estimated. Water use projections for 1990 and 2000 were estimated from those projections adjusted to reflect actual water use in 1980 and changes in population projections since that report. Population projections for individual cities and villages shown in Table 3 were computed on the assumption that growth would be proportional to the increase in total county population for 1990 and 2000 projected by the State of Illinois Bureau of the Budget (1980).

Per capita consumption rose rapidly from 1940 to 1960. There was less increase in per capita consumption from 1960 to 1970, and per capita consumption has leveled off during the 1980s. Public water supply systems of cities such as Streamwood and Valley View have little or no industrial services and report per capita consumption less than the average. City systems which serve industry, such as in Elgin and St. Charles, report per capita consumption higher than the average.

There are numerous wells owned and operated by self-supplied industries in the study area. Typically, withdrawals from these wells are small compared to withdrawals from public water supply wells. In the

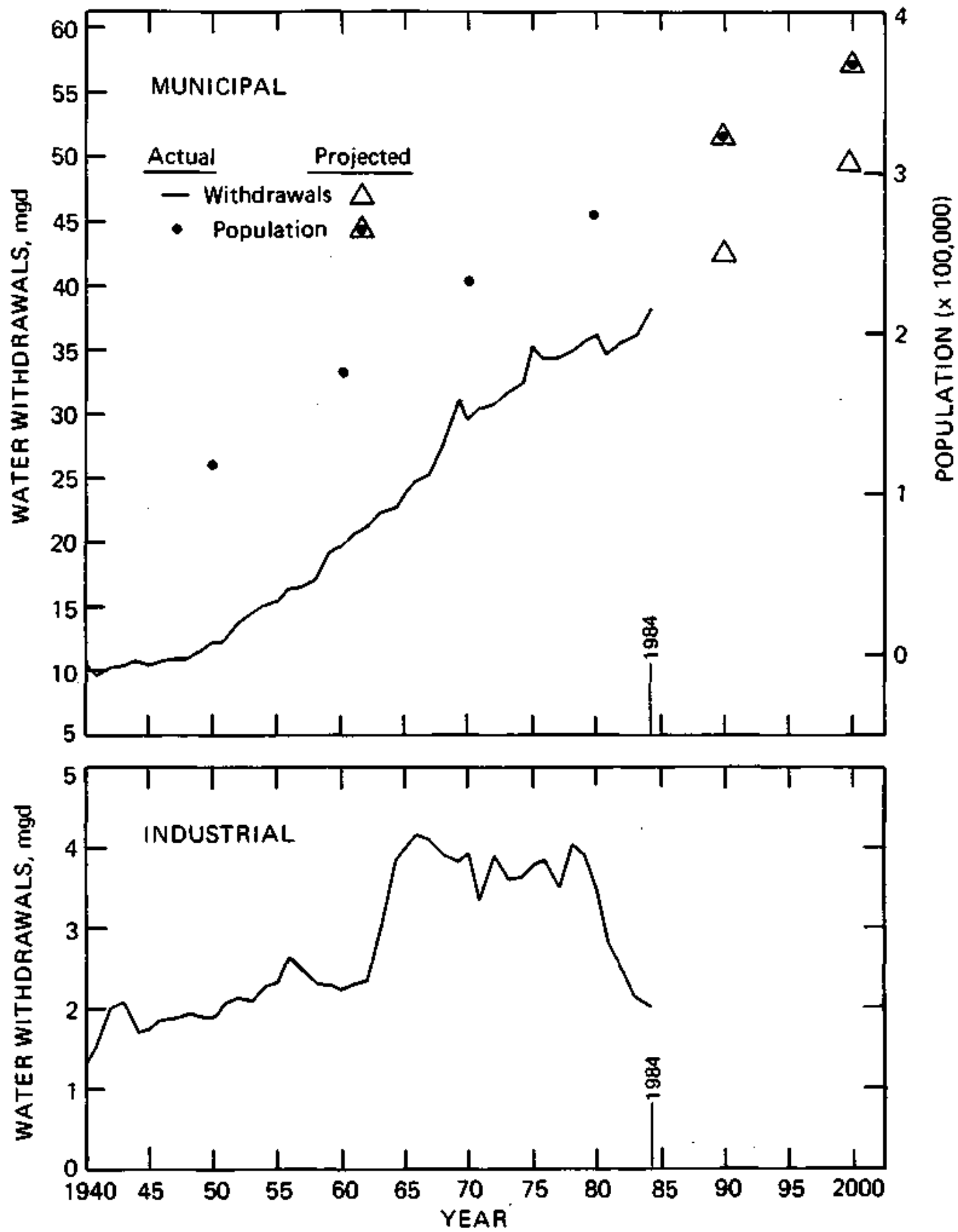

Figure 2. Average daily pumpage and population trends from 1940-2000

Elgin-Carpentersville area there are industrial wells tapping local deposits of sand and gravel. Industrial wells open to the Silurian dolomite are common in the St. Charles-Geneva-Batavia area. The Silurian dolomite aquifer is the principal source used in the Aurora area. In 1984, 78% of the total ground-water pumpage for self-supplied industries in Kane County was obtained from Silurian dolomite near Aurora (Kirk et al., 1984). Water withdrawals by self-supplied industries averaged 3.298 mgd: 1.300 mgd from surface water, 0.423 mgd from the Cambrian-Ordovician aquifer, 1.561 mgd from the Silurian dolomite aquifer, and the remainder from sand and gravel deposits (Kirk et al., 1984).

Increasingly, industries have been reducing their water demands by instituting conservation measures (Sasman, 1970). Numerous industries have closed down their wells and switched to nearby city systems. Self-supplied industrial water use in the area has been declining since 1979.

Wastewater Treatment Plants

There are 14 municipal and semi-public treatment plants serving the study area communities as well as treatment plants operated by the Illinois Youth Center at St. Charles and the Mooseheart Home (listed in Table 5). The average effluent discharges for 1984 are also listed in Table 5. Parts of Aurora, Batavia, Carpentersville, and Elgin have combined sanitary and storm sewer systems; thus yearly average discharges from these treatment plants will include some storm runoff and greater ground-water infiltrations than non-combined systems. The bulk of wastewater treated at the facilities originates as ground water pumped by the various city water supply operations. The facilities also receive wastewater from numerous self-supplied industries and individual private consumers who obtain their water from private wells.

The Aurora Sanitary District facilities receive and treat wastewaters from North Aurora and Montgomery. The Elgin treatment plants receive wastewater from South Elgin, Streamwood, and the Elgin State Hospital. Streamwood operated a treatment plant until 1977. The Elgin west plant was owned and operated by the Elgin State Hospital until 1983.

Table 5. Wastewater Treatment Plants

Municipal or semi-public treatment plant	1984 average discharge (mgd)
Algonquin Sanitary District	1.10
Aurora Sanitary District	24.45
Batavia Sanitary District	2.25
Carpentersville Sanitary District	
Main Plant	2.68
Kimble Hill Plant	0.08
East Dundee Sanitary District	0.68
Elgin Sanitary District	
North Plant	3.07
South Plant	13.83
West Plant	0.53
Ferson Creek Utility Company	.06*
Geneva Sanitary District	2.35
St. Charles Sanitary District	4.04
St. Charles Skyline Sewer and Water Corp. (Valley View)	.07*
West Dundee Sanitary District	0.89
Illinois Youth Center - St. Charles	0.13*
Mooseheart Home	0.11*

*Estimated from 1982 data

Data source: Illinois Environmental Protection Agency effluent discharge sheets

Several industries discharge cooling water to ditches and creeks near the Fox River and directly into the Fox River. Generally this water is not treated. There are no major industrial waste treatment plants currently operating in the study area. (The Armour Dial Plant near Aurora discharges to Blackberry Creek, which joins the Fox River downstream of the study area.)

VARIATIONS IN BASEFLOW ACCRETIONS

There are numerous shallow aquifers in sand and gravel and Silurian dolomite along the Fox River in Kane County. When these aquifers are in hydraulic connection with the river, their water levels will interact with the water levels in the river. During low river flow conditions, discharge from these aquifers will contribute to the baseflow of the river. Large withdrawals from a hydraulically connected aquifer may reduce this discharge, and in extreme cases ground water levels may decline so much that the river may lose water to the aquifer. Variations in the baseflow of the river are indicative of any interaction with shallow aquifers along the river.

Baseflow forms a greater portion of the total river flow during low-flow periods. During dry weather conditions, surface runoff is diminished and river flows are less variable. Two independent sets of low-flow measurements were made on the Fox River and its tributaries in the study area during relatively dry weather. In addition to the field measurement of discharges, effluent flows from various wastewater treatment plants and water withdrawals at Elgin during the two measurements were obtained from the operating agencies. Evaporation losses from instream pools were also estimated. Water budgets were developed from the data collected, and the results were used to evaluate the variation in baseflow along the river.

Field Measurements

Study Reaches

Detailed discharge measurements during each flow event were made at 5 cross sections on the Fox River, from upstream of Algonquin to downstream of Aurora. The 5 transects segment the river into 4 reaches. The portion of the river from transect 1 to transect 2 is reach A, the reach defined by transects 2 and 3 is B, and so on. Table 6 lists the locations of the transects, the reach designations, and other descriptive information. The measured discharges and hydraulic characteristics are shown in Table 7. The transect locations are shown in Figure 3.

The transects were located so as to define 4 reaches with unique conditions. Reach A, from Algonquin to Carpentersville, extends through the region which has the greatest water withdrawals from shallow aquifers. The area adjacent to reach B has little pumpage from shallow aquifers and

Table 6. Study Reaches

Reach	Transect no.	Location	River mile	Drainage area (sq mi)
	1	Downstream of Crystal Creek, above Algonquin	81.6	1403
A				
	2	Downstream of Main St. bridge connecting East & West Dundee	76.1	1447
B				
	3	Downstream of Interstate 64 bridge at St. Charles	59.6	1665
C				
	4	Downstream of the North Aurora Dam	51.9	1690
D				
	5	At Riverside Cemetery, Riverside	45.9	1732

Table 7. Measured Discharges and Hydraulic Characteristics

Date/Time start/end	Transect	Q(cfs)	A(sq ft)	W(ft)	V(ft/sec)	D(ft)
August 20						
0900 1045	1	503.2	204.4	116.5	2.46	1.75
1240 1420	2	478.2	323.1	134.5	1.48	2.40
1535 1625	3	581.2	326.5	236.2	1.78	1.38
August 21						
0850 0945	3	562.2	314.6	232.9	1.79	1.35
1030 1215	4	516.2	329.9	218.2	1.56	1.51
1430 1615	5	529.7	525.5	224.7	1.01	2.34
September 18						
1000 1105	1	400.2	174.8	108.3	2.29	1.61
1250 1405	2	389.6	284.7	131.2	1.37	2.17
1530 1635	3	458.1	277.5	226.4	1.65	1.23
September 19						
0945 1100	3	475.2	280.2	226.4	1.70	1.24
1245 1420	4	452.3	285.9	210.0	1.58	1.36
1530 1645	5	451.6	366.9	206.7	1.23	1.78

Note: Q = discharge; A = cross-sectional area of flow; W = top width; V = Q/A, average velocity; D = A/W, average depth

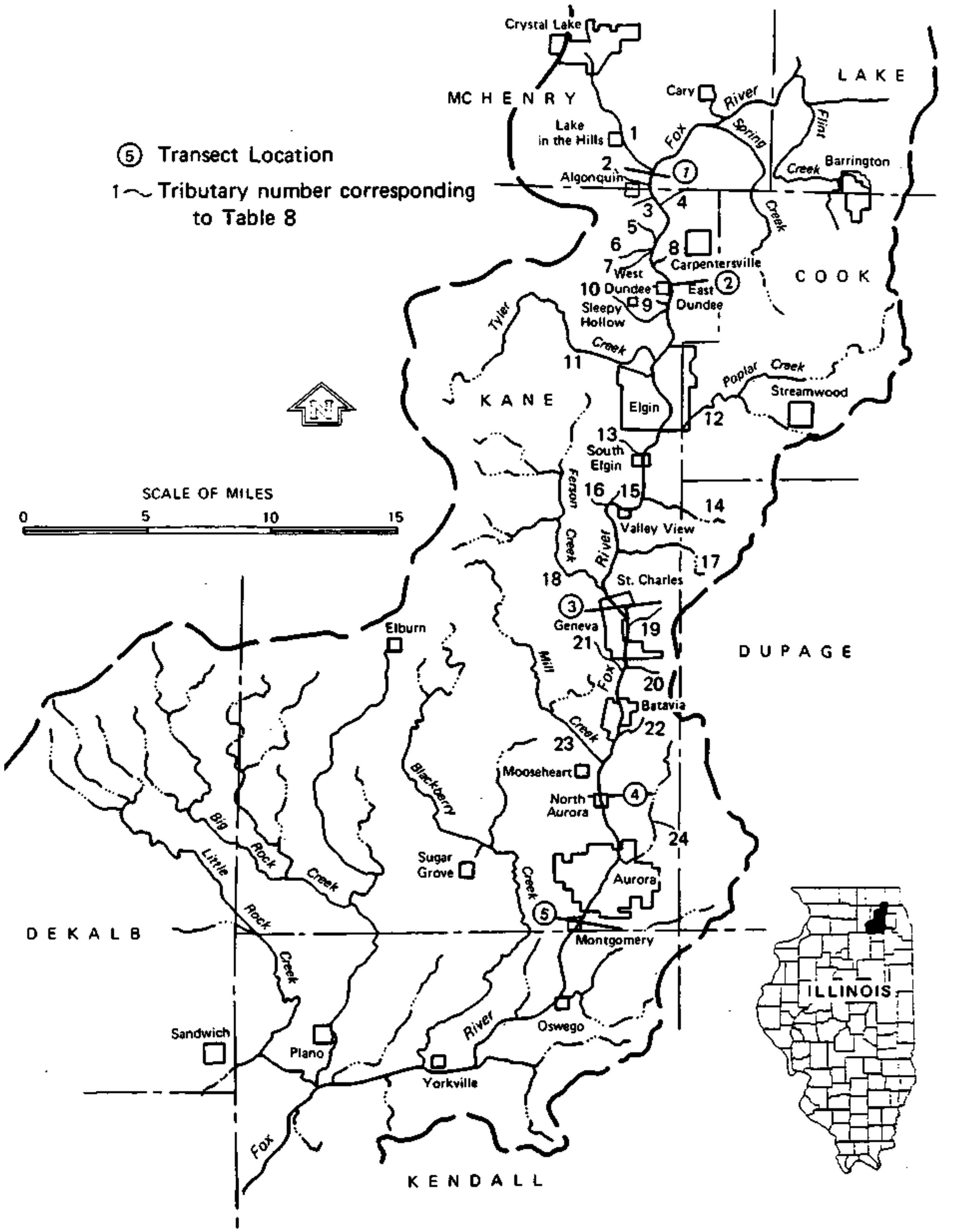

Figure 3. Fox River stream network and field measurement sites

includes Elgin's surface water intakes. St. Charles, Geneva, and Batavia are all within the bounds of reach C. These communities currently utilize the deep sandstone aquifer as their primary water source and may benefit by switching to shallow aquifers if available. St. Charles withdraws some water from sand and gravel deposits and there are some industrial wells finished in the dolomite aquifer along reach C. In the Aurora area, which is adjacent to reach D, there are water withdrawals from the dolomite aquifer (industrial wells) and virtually no withdrawals from aquifers in sand and gravel. Pumpage from wells serving Aurora, North Aurora, and Montgomery accounts for approximately 50% of withdrawals from the deep sandstone aquifer in the current study area.

Procedures and Data Collected

Main channel and tributary discharge measurements were conducted on two consecutive days for each flow event. The first set of data (event 1) was taken on August 20 and 21, 1985 and the second (event 2) on September 18 and 19, 1985. The flows at the USGS gaging station at Algonquin on the mornings of August 20 and September 18 were 510 cfs and 390 cfs, respectively. These flows correspond to annual flow durations of approximately 56 and 67%.

Raingage stations at Antioch, McHenry, Elgin, Barrington, and Aurora in the study area had no precipitation during the periods August 16-21 and September 12-19. On August 13, 1985 there was a storm yielding an average 1.84 inch rainfall at the above stations, and on August 15, 1985 another separate storm averaged 0.39 inches in the area. On September 9 and 10 there was a storm averaging 1.24 and 0.04 inches per day, respectively. The rainfall data indicate a dry period of 4 days before the first set of measurements was taken in August and a dry period of 6 days before the September measurements. The rainfall data were obtained from the U.S. Weather Bureau's monthly summaries for Illinois.

The gates at McHenry Dam were held at a constant opening for 6 to 7 days prior to the fieldwork as well as during the fieldwork. Thus the flow releases from the McHenry Dam were held practically constant.

On the first day, discharge measurements at transects 1, 2, and 3 were made and the discharges of all tributaries upstream of transect 3 were also measured. The following day the discharges at transects 3, 4, and 5 as well as the flow in all tributaries between transects 3 and 5 were measured. Tributary flows were measured just upstream of their mouths.

All discharge measurements were performed by wading across the river to obtain depth and velocity values. Depth and velocity were measured every 4 to 6 feet across the river width, typically resulting in an average of 25 measurements for each transect. The high-density sampling was conducted in order to provide the most accurate evaluation of discharge.

The discharges measured at each transect as well as the average velocity, flow area, depth, and width are presented in Table 7. The data are given in chronological order, and the dates and beginning and ending times of the measurements are also shown.

The discharges measured at the mouths of tributaries for each event are listed in Table 8. The locations of the 24 tributaries identified are shown in Figure 3. Each tributary is numbered in the figure, and the numbers correspond to those in Table 8.

Water Budget

A water budget was developed for each reach. Factors included in the budget are 1) inflow and outflow, measured at the upstream and downstream transects respectively, 2) tributary inflows, 3) effluent flows from treatment plants, 4) surface water withdrawals, 5) evaporation losses, and 6) variability of the flows during the course of the measurement.

Differences between the discharges measured at the upstream and downstream transects defining the limits of the reach may in part be accounted for by the factors noted above. Once the quantities of known inflows and losses along the reach are determined, the remaining difference may reflect a variation in baseflow. A net gain along a reach may indicate that shallow aquifers are contributing to the baseflow of the river. A net loss in a reach may indicate lower sustained flows during dry periods and possibly loss of stream water to shallow aquifers due to reverse gradients (flow from river to ground-water aquifers).

Effluent Discharges, Surface Water Withdrawals, and Evaporation Losses

There are 13 treatment plants discharging effluents into the river within the study reaches defined by the field measurements. Each plant was contacted by phone to obtain the discharge volume from the plant on the

Table 8. Tributary Flows

Tributary number		August 20	September 18
1	Crystal Creek at Algonquin (upstream of Section 1)	5.00	5.76
Reach A			
2	Unnamed (south of Algonquin, McHenry Co.)	0.15	0.12
3	Unnamed (south of Algonquin, Kane Co.)	0.14	0.13
4	Unnamed (northeast of Carpentersville)	0.12	0.07
5	Unnamed (west of central Carpentersville)	0.09	0.09
6	Unnamed (southwest of Carpentersville)	0.00	0.10
7	Unnamed (southwest of Carpentersville)	0.11	0.14
8	Unnamed (southwest of Carpentersville)	0.04	0.14
	Reach Total	0.65	0.79
Reach B			
9	Unnamed (south of West Dundee)	0.76	0.48
10	Jelkes Creek	2.56	2.53
11	Tyler Creek	4.51	2.42
12	Poplar Creek	16.09	5.57
13	Unnamed (southwest of Elgin)	0.11	0.07
14	Brewster Creek	0.23	2.72
15	Unnamed (near Fox River Estates)	0.05	0.22
16	Unnamed (north of Novak Park)	0.05	0.00
17	Norton Creek	0.16	4.25
18	Ferson Creek	10.66	9.73
	Reach Total	35.18	27.99
Reach C			
19	Unnamed (northeast of Geneva)	0.00	0.87
20	Unnamed (southeast of Geneva)	0.03	0.00
21	Unnamed (southwest of Geneva)	0.07	0.61
22	Unnamed (south of Batavia)	0.00	1.46
23	Mill Creek	1.87	1.97
	Reach Total	1.97	4.91
Reach D			
24	Unnamed (north of Aurora)	0.00	0.18
	Reach Total	0.00	0.18

days of the fieldwork. Discharges from the various plants measurably alter the river flow volume, and inclusion of the effluent flows in the water budget is essential. In most cases the reported value was the total volume of outflow for the 24-hour period. In order to determine an hourly rate, it was assumed that the total volume was uniformly discharged over the 24-hour period. Table 9 shows the treatment plant effluent values.

Table 9. Treatment Plant Effluent Discharges
(All values are in cfs)

	August 20	August 21	September 18	September 19
Reach A				
Algonquin	1.965	1.872	2.042	1.903
Carpentersville:				
Kimble Hill Plant	0.135	0.119	0.179	1.183
Main Plant	3.280	3.435	3.466	3.249
Total	5.380	5.426	5.687	5.335
Reach B				
East Dundee	0.995	0.936	0.986	1.037
West Dundee	1.187	1.198	1.199	1.182
Elgin: North Plant	4.441	4.471	4.332	4.518
South Plant	19.294	17.901	18.103	17.329
West Plant	0.805	0.727	0.712	0.866
Valley View	0.930	0.930	0.930	0.930
Total	27.652	26.163	26.262	25.862
Reach C				
St. Charles	4.796	4.301	4.673	4.843
Geneva	2.940	2.940	2.940	2.940
Batavia	3.410	2.007	2.785	3.094
Mooseheart	0.125	0.128	0.109	0.106
Total	11.271	9.376	10.507	10.983
Reach D				
Contains no treatment plants				

During the time of the fieldwork, Elgin was withdrawing water from the river. The quantities reported by the Elgin Water Department were 0.93 cfs in August and 3.44 cfs in September.

The numerous pools created by the instream dams expose a large surface area of water to evaporation. Evaporation rates were obtained from the lake evaporation rates reported by Roberts and Stall (1967). Losses due to evaporation were calculated on the basis of water surface areas from USGS 7-1/2-minute topographic maps and design details for the impoundments (Illinois Division of Waterways, Department of Public Works and Buildings, 1962). The total volume of evaporation for a one-month period was assumed to be uniformly distributed during the month. Details of these calculations are not presented here, but the results are presented in the water budget.

Flow Variability

Gage heights recorded at the USGS gage at Algonquin before and during the fieldwork show that the flow was not steady (Tom Richards, USGS, personal communication, 1986). The Illinois Department of Transportation, Division of Water Resources (DWR) maintains three gages at locations along the study reach. Gages are located at the South Elgin Dam, at the dam at Geneva, and at the Montgomery Dam. Gage height records at these sites help in delineating the flows below the Algonquin gage (Paul Kramer, IDOT, personal communication, 1986). Differences due to unsteady flow were included in the water budget.

The flow travel time between transects does not equal the time difference between the measurements. Thus the five discharges measured in the main channel for each event correspond to different points in time on the inflow hydrograph constructed from the Algonquin gage data.

For both events, the travel time between the Algonquin gage and transect 3 was approximately 20.0 hours and the travel time between the Algonquin gage and transect 5 was approximately 33.5 hours. The flow measured at transect 3 would have passed the Algonquin gage nearly a day earlier. The flow measured at transect 5 would have passed through Algonquin 1-1/2 days earlier. Thus the period of interest recorded at the Algonquin gage is about a day earlier than the times of the field measurements.

Hourly gage heights are not available for the period of interest in August because of a malfunction of the recorder. A synthesized gage height record was provided by the USGS. The synthesized record is based on gage heights obtained through the National Weather Service, which monitors the gage at 6-hour intervals. Gage heights vary between 1.36 and 1.38 ft during the time enveloping the passing hydrograph. The corresponding discharges are 501.7 and 526.1 cfs respectively.

Between noon on September 17 and 6:00 p.m. on September 18, the Algonquin gage height varied from a minimum of 1.23 ft to a maximum of 1.29 ft. The corresponding discharges from the rating table developed by the USGS are 360.1 cfs and 422.6 cfs. This time period envelops the hydrograph passing through the reach at the time of the fieldwork.

Lag time routing was used to develop hydrographs for the transect sites from the gaging station records. The Algonquin gage was used for reach A, the South Elgin gage for reach B, the Geneva gage for reach C, and the Montgomery gage for reach D. Flow travel time between gages and transects was estimated by dividing the distance between the points by the average velocity of the reach. The reach average velocity was computed as the arithmetic mean of the average velocity measured at the upstream and downstream transects. On the basis of the travel time computed, the gage time corresponding to the time of the field measurement was determined. For transects upstream of the gage, the travel time (lag time) was added to the time of the field measurement to obtain the corresponding gage time. The travel time was subtracted from the actual measurement time for transects downstream of the gage. The gage discharge corresponding to each transect measurement was determined from the stage record and the gage rating table. An average gage discharge was computed by examining the flows recorded during the time (1 to 1-1/2 hours) required to measure the discharge at a transect. The measurement times, reach average velocities, travel times, and corresponding gage times and average discharges are shown in Table 10. The difference between the routed discharges (average gage Q) for the downstream and upstream transects is Q_v. The value of Q_v is positive if the gage discharge corresponding to the downstream transect measurement is larger than the gage discharge corresponding to the upstream transect measurement. The values of Q_v are shown in the table and were included in the water budget calculations. Attenuation of the hydrograph between the transects should be minimal due to the proximity of the gages to the transects.

The numerical values of the discharges derived from the gaging station records and adjusted for known inflows and outflows do not always agree with the field-measured discharges. The differences are attributed

Table 10. Hydrograph Routing and Calculation of Q_v

Reach	Transect no.	Field measurement Date	Field measurement Start time (hrs/mins)	Field measurement End time (hrs/mins)	V	Gage	Travel time	Corresponding gage Date	Corresponding gage Start time (hrs/mins)	Corresponding gage End time (hrs/mins)	Average gage Q	Q_v
August												
	1	8-20	09:00	10:45		USGS at	0	8-20	09:00	10:45	518.2	
A					1.97	Algonquin						+1.0
	2	8-20	12:40	14:20			-4:05	8-20	08:35	10:15	519.2	
	2	8-20	12:40	14:20		DWR at	+7:55	8-20	20:35	22:15	534.5	
B					1.63	South Elgin						+3.5
	3	8-20	15:35	16:25			-6:56	8-20	08:39	09:29	538.0	
	3	8-21	08:50	09:45		DWR at	+1:29	8-21	10:19	11:14	536.0	
C					1.67	Geneva						+12.0
	4	8-21	10:30	12:15			-5:16	8-21	05:14	06:59	548.0	
	4	8-21	10:30	12:15		DWR at	+6:49	8-21	17:19	19:04	557.0	
D					1.29	Montgomery						+6.0
	5	8-21	14:30	16:15			0	8-21	14:30	16:15	563.0	
September												
	1	9-18	10:00	11:05		USGS at	0	9-18	10:00	11:05	390.9	
A					1.83	Algonquin						+11.5
	2	9-18	12:50	14:05			-4:25	9-18	08:25	09:40	402.4	
	2	9-18	12:50	14:05		DWR at	+8:33	9-18	21:23	22:38	419.0	
B					1.51	South Elgin						-10.5
	3	9-18	15:30	16:35			-7:29	9-18	08:01	09:06	408.5	
	3	9-19	09:45	11:00		DWR at	+1:31	9-19	11:16	12:31	456.5	
C					1.64	Geneva						+19.5
	4	9-19	12:45	14:20			-5:22	9-19	07:23	08:58	476.0	
	4	9-19	12:45	14:20		DWR at	+6:14	9-19	18:59	20:34	437.5	
D					1.41	Montgomery						+7.5
	5	9-19	15:30	16:45			0	.9-19	15:30	16:45	445.0	

to limitations in rating table accuracy and resolution of the gage recorder. However, only the changes in discharge, indicated by gage height, were used in the water budget calculations.

Calculations

Water budgets were computed for each of the four reaches for both flow events. The discharge measured at the reach upstream transect is the inflow, I. The discharge measured at the downstream transect is the outflow, 0. Inflows and losses along the reach for which the quantities are known or estimated are the sum of the tributary flows Q_T, the sum of effluent discharges Q_{EFF}, water withdrawals Q_W, and evaporation losses Q_E. The differences between the gage hydrograph discharges, Q_V, corresponding to the downstream and upstream transect measurements were computed and added to the inflow. The Q_V may be positive or negative depending on whether the hydrograph flow corresponding to the downstream transect was greater or less than the upstream transect flow. The difference between reach outflow, 0, and the inflow, I, not accounted for by the above-noted reach gains and losses, is AQ. Assuming that all inflows and losses to the reach are identified and accurately quantified, AQ is attributable to baseflow, Q_B. Variations in baseflow (flow gains or losses through seepage) are affected by the streamflow interaction with the ground-water table.

The water budget calculations are mathematically expressed as:

$$0 - (I + Q_T + Q_{EFF} + Q_W + Q_E + Q_V) = \Delta Q$$

$$Q_B = \Delta Q \pm E, \text{ where } E = \text{accumulated error}$$

The quantities for each reach are listed in Table 11. The change in baseflow (flow gain or loss per mile) was computed for each reach by dividing AQ by the reach length. These values are listed in Table 12.

The water budgets for reaches A and B were computed by using the measured discharges on the first day of the two-day fieldwork and the inflows and withdrawals reported for that day. The water budgets for reaches C and D were computed by using the information collected the second day of the fieldwork.

Table 11. Water Budgets for Study Reaches
(All values in cfs)

Period: August 20-21, 1985

Reach	0 (1)	I (2)	Q_T (3)	Q_{EFF} (4).	Q_W (5)	Q_E	Q_V (7)	Sum of Col. 3-7 (8)	ΔQ Col.l less Col. 2-7 (9)
A	478.2	503.2	0.65	5.38	0	-1.18	+1.0	+5.85	-30.9
B	581.2	478.2	35.18	27.65	-0.93	-4.91	+3.5	+60.49	+42.5
C	516.2	562.2	1.97	9.38	0	-2.36	+12.0	+20.99	-67.0
D	529.7	516.2	0	0 .	0	-0.80	+6.0	+5.20	+8.3

Period: September 18-19, 1985

Reach	0 (1)	I (2)	Q_T (3)	Q_{EFF} (4)	Q_W (5)	Q_E (6)	Q_V (7)	Sum of Col. 3-7 (8)	ΔQ Col.l less Col. 2-7 (9)
A	389.6	400.2	0.79	5.69	0	-0.83	+11.5	+17.15	-27.8
B	458.1	389.6	27.99	26.26	-3.44	-2.32	-10.5	+37.99	+30.5
C	452.3	475.2	4.91	10.83	0	-1.64	+19.5	+33.60	-56.5
D	451.6	452.3	0.18	0	0	-0.54	+7.5	+7.14	-7.8

Table 12. Baseflow Loss or Gain per Mile

Reach	Length (mi)	Aug. 20-21, 1985 ΔQ/length (cfs/mi)	Sept . 18-19, 1985 ΔQ/length (cfs/mi)
A	5.5	-5.6	-5.1
B	16.5	+2.6	+1.8
C	7.7	-8.7	-7.3
D	6.0	+1.4	-1.3
Total length	35.7	-1.3	-1.7

Error Analysis

There are certain inherent limitations to the accuracy of the water budgets calculated. The magnitudes of various sources of error were examined and compared to the magnitude of the loss or gain computed for the study reaches.

The accuracy of the discharge computed from the field measurement of depths and velocities increases with the number of measurements made while traversing the cross section (Carter and Anderson, 1963). It is commonly assumed that errors are less than 5%. Following Carter and Anderson's estimation of percent error as a function of the number of measurements in a cross section, the discharges measured in the field should be accurate within 2.5%. The maximum expected error in the Fox River discharges is 15 cfs for the August data and less for the September data. Applying the 5% rule, the maximum error of the tributary contributions for each reach is under 2 cfs.

Effluent discharges, reported water withdrawals, and evaporation losses calculated are daily averages. The exact quantity for a specific time is unknown. The largest effluent inflows, the greatest evaporation loss, and the only water withdrawal from the river occur in reach B. Thus the calculations for reach B have the maximum potential for error. Hypothesizing that the average values are within 20% of the actual values, the maximum error (for Reach B) is about 6.5 cfs. The possible errors in discharge measurements, effluent discharges, water withdrawals, and evaporation losses are random and as such would probably not combine to form a worst case of the order of 20 cfs.

The evaluation of discharge differences due to unsteady flow is very sensitive to the estimation of the lag time. The accuracy of the relation between changes in gage height and changes in discharge will also contribute uncertainty. Hydrographs routed to the transects were examined to determine the range of discharges occurring between 6 hours before and after the time of the measurements. Flows within this 12-hour time period differed from the discharge used by a maximum of about 15 cfs.

In only one case (that of reach D in August), the potential error in the Q estimate was sufficiently large to change the sign of ΔQ, For this case AQ would change from +8.3 cfs to -7 cfs. A net loss in this reach during August would be consistent with the net loss calculated from the data collected in September.

The instream dams located within the study reach will enhance attenuation of the passing hydrograph, as pools created by these dams serve to increase channel storage. When inflow decreases, pool storage decreases and the change in storage, AS, is picked up as a positive contribution to the outflow (at the dam) until equilibrium is reached (or flow starts to increase). Conversely, as inflow increases, pool storage increases and the change in storage, AS, is negative until equilibrium is reached (or flow begins to decrease). Hydrographs routed downstream may have overestimated rising limb flows and underestimated falling limb flows. Similarly, hydrographs routed upstream may show underestimated rising limb flows and overestimated falling limb flows.

The storage factor cannot be included in the water budget calculations in a straightforward manner because the flows measured at the transects correspond to different times on the inflow hydrograph. Hydrographs routed from the gaging stations to the measured transects must be adjusted to account for changes in channel storage. Errors in hydrograph discharges due to neglect of storage attenuation will affect the computed Q .

Evaluation of channel storage and hydrograph attenuation would require flow modeling of the river, which is beyond the scope of this project. The Algonquin gage and the three DWR gages are located at dams and therefore changes in gage height (pool) indicate changes in channel storage. As noted earlier, changes in gage height recorded at the Algonquin dam were not large: the maximum differences were 0.02 ft in August and 0.06 ft in September for the hydrographs, which spans all measurements. Differences in gage heights recorded at the DWR gages are less than at the Algonquin gage, and these differences decrease in the downstream direction. An estimation of the maximum change in channel storage was made to assess an upper limit for error arising from neglect of hydrograph attenuation.

The maximum change in gage height, Ah, recorded at each of the gages was determined for times (adjusted for lag time) corresponding to measurements made at the adjacent transects. The total pool surface area (A) between a field-measured transect and the gage from which the hydrograph was routed was calculated. The estimate of maximum change in channel storage between the transect and this gage was computed by multiplying the pool area by the maximum Ah recorded (i.e., the largest Ah recorded at a gage adjacent to the measured site). The change in storage volume was converted to discharge, Q_s, by dividing the change in storage volume by the travel time, At (i.e., lag time) used for the hydrograph routing. This is expressed by:

$$AS = A \bullet Ah$$

$$Q_s = \frac{\Delta S}{\Delta t}$$

The flows measured in August appear to be on a gradually falling limb. Storage would be decreasing and generally this would tend to increase the difference between the discharge from the estimated hydrograph downstream and the upstream discharge, and Q_v would be larger. A positive increase in Q_v would be a negative contribution to AQ. The estimated maximum changes in AQ are -12, -15, -27, and -4 cfs for reaches A through D, respectively. These adjustments would not appreciably alter the trend in baseflow accretions in the four reaches.

Flows were more variable during the September fieldwork, and some measurements were made during increasing flow and some while the flow was decreasing. Because of small undulations in the discharge, errors in the lag time could shift the routed hydrograph so as to change the corresponding measurement from an increasing flow period to a decreasing flow period or vice versa. Changes in Q_v were estimated for both possibilities when necessary. Maximum changes in AQ are on the order of those for August.

Discussion

Because of inherent errors in the calculation of the water budgets, the values of flow loss or gain provide only a qualitative assessment of trends in baseflow. The consistency of the results for each reach for both field studies supports the reliability of the trends indicated.

The AQ values for the four reaches are given in Table 11, and the flow losses and gains per mile are shown in Table 12. The values indicate that there are flow losses in reach A from Algonquin to East and West

Dundee, reach B from East and West Dundee down to St. Charles is gaining flow, reach C between St. Charles and Geneva is losing flow, and reach D is most likely also losing flow. Considering only the trend indicated by these values, reach B would appear to have higher baseflow accretion than the other reaches.

Reach B includes the portion of the river passing Elgin and South Elgin, but the greater portion of the reach passes through a relatively undeveloped area with no wells. Apparent losses in the other reaches may be attributable to lower baseflow accretions and/or loss of river water to hydraulically connected shallow aquifers with lowered water tables because of excessive pumping.

INSTREAM WATER QUALITY

Water quality in the Fox River basin varies from fair to good. Trends in water quality indexes developed by the Illinois Environmental Protection Agency (IEPA) indicate that water quality improved over the period 1978 to 1985 (IEPA, 1986). On the basis of water quality indices, the Fox River basin was rated second-highest in water quality in the state.

The streams in the Fox River basin are subject to two sets of standards established by the Illinois Pollution Control Board (IPCB) and administered by the IEPA. The IEPA has designated all streams in the Fox basin in Illinois as "general use," and as such the Illinois general use standards apply to all points. These standards are intended to protect aquatic life, contact recreation, and agricultural and industrial uses. Illinois public water supply standards apply only at locations where water is withdrawn for public supply. Elgin is currently the only location where these standards are in force.

General use and public water supply standards are applicable to instream flows. Effluent discharges from treatment plants are subject to different criteria. The emphasis of this initial study is to determine the effect of reduced low flows on the quality of the instream flow and to provide a general assessment of the quality of the water available for withdrawals. Ambient (instream) water quality data are reviewed. Compliance records of individual treatment plants, management practices, and treatment levels are not discussed in detail.

Water quality data and relevant reports summarizing water quality conditions in the basin were reviewed to develop a general understanding of the trends in water quality in the basin. Water quality is assessed in terms of compliance with both sets of standards discussed above. Water quality parameters which have consistently exceeded the standards are discussed. Parameters which currently do not exceed the standards but which may reach noncompliance levels if flows are reduced are also noted.

Sources of Data

The IEPA, in cooperation with the U.S. Geological Survey, operates the Ambient Water Quality Monitoring Network (AWQMN). There are 10 ambient water quality monitoring stations in the Fox basin in Illinois which are currently active: 6 along the main channel, and 4 on tributary streams.

The 6 stations located on the main channel are listed in Table 13, with their USGS and IEPA designations. Water quality data have been collected at or near these stations throughout the period 1970 to 1985. Typically one sample is taken every 6 weeks at each station and the concentrations of approximately 60 constituents are measured.

Table 13. Ambient Water Quality Monitoring Stations on the Fox River

USGS gage no.	IEPA station	Location
5546700	DT35	Fox River, Rt. 173 near Wisconsin line
5549600	DT22	Fox River, Rt. 176, Burton's Bridge
5550000	DT06	Fox River, Rt. 62, Algonquin
5551000	DT09	Fox River, State Street, South Elgin
5551540	DT38	Fox River, Mill Street, Montgomery
5552500	DT46	Fox River, County Highway 18, Dayton

Several studies of the water quality of the Fox River basin have been conducted covering various segments of the period 1970 to 1985. Water quality data for the period 1958 to 1975 have been graphically summarized for various parameters by the Northeastern Illinois Planning Commission (Elmore et al., 1977). Concentration levels and applicable standards are plotted versus time, and these show time-related trends. From April 1976 through December 1977 the Northeastern Illinois Planning Commission (NIPC, 1978) conducted an intensive water quality sampling program. The data collected were used to calibrate the Hydrocomp computer model. The model was then used to simulate selected parameter concentrations for sub-reaches along the Fox River in Illinois for a 3-year period. The results of the computer simulation provide a more comprehensive picture of water quality than the sampling programs. Flemal (1983) compared station water quality data to the general use and water supply standards, tabulating a record of percent violations for the period January 1974 through December 1981. The IEPA compiled information on water quality and locations of wastewater treatment plant discharges and other facilities whose operation may influence water quality. This information is presented In the Water Quality Management Basin Plan (IEPA, 1976). The IEPA conducted an intensive basin survey in 1982 and 1983 (IEPA, 1984). These studies together with the station data for the period 1982-1985 were used to assess water quality for the study period.

Compliance with Illinois Pollution Control Board Standards

The general use standards (IPCB, 1982) define concentration limits for 26 water quality parameters. Basinwide compliance with these standards has generally been good. The public water supply standards (IPCB, 1982) establish concentration limits for 28 water quality parameters. The water supply standards are the same as or more restrictive than the general use standards for the Fox River.

In the Fox River iron, phosphorus, and fecal coliform bacteria are the only parameters in frequent and continuing violation of the standards. To a much lesser extent, measured concentrations of copper, lead, manganese, ammonia, and dissolved oxygen have periodically been in violation of the standards.

Iron concentrations in the Fox basin are generally lower than is typical for other Illinois regions (Flemal, 1983). However, concentrations are frequently in excess of the 1000 μg/1 limit established by both sets of standards. For the period 1974 to 1981 Flemal reports violation rates of 17% near the Wisconsin-Illinois border, no violations at Burtons Bridge in McHenry County at Algonquin, only a 4% violation rate at South Elgin, and violations occurring 30% and 24% of the time at Montgomery and Dayton, respectively. Water quality samples collected from 1982 through 1985 show violations between 15 and 20% for stations from the Wisconsin border down to South Elgin and violation rates greater than 30% at Montgomery and Dayton, respectively. Iron found in the Fox River is principally derived from geochemical ferrous iron which is dissolved in ground water and seeps into the streams as part of the baseflow. Iron concentration levels increase with discharge. This appears to be attributable to a flushing of iron from the streams as a result of high surface runoff and velocities sufficient to scour the stream bed. Thus iron concentration violations are a high-flow problem.

The single standard of 0.05 mg/1 for phosphorus applies to lakes and reservoirs. None of the ambient water quality stations are in locations where the standard applies. However, the consistently high concentrations of phosphorus found at the stations indicate that the standard for phosphorus is not met in reservoir reaches. Virtually all samples collected from 1970 to 1985 have phosphorus concentrations exceeding the standard. Phosphorus enters the streams from point and non-point sources as well as by natural processes. Background levels may be sufficiently high that even if phosphorus introduced from agricultural and urban activities were eliminated, the standard could not be met (Flemal, 1983).

Fecal coliform bacteria colony counts increase dramatically in the downstream direction as the Fox River passes through the highly urbanized area in Kane County. Both sets of standards set a limit of 200 colonies per 100 ml. The percent of violations has also increased over the years downstream of Algonquin. The percentages of samples in violation for the period 1974-1981 at Algonquin, South Elgin, and Montgomery (Flemal, 1983) were 14, 69, and 78%, respectively. For the period 1982-1985 the violations were 21, 60, and 94%, respectively. There are few effluent discharges below Montgomery, and fecal coliform concentrations are more dilute by the time the flow reaches Dayton; however, violations have increased and for the two time periods they are 34 and 60%. The presence of fecal coliforms serves as an indication that the sanitary quality of the water has been degraded through the discharge of incompletely treated wastewater.

Both sets of standards set copper concentration limits of 20 μg/1. Violations of the standard are recorded for the period prior to 1978 and for the sampling conducted by NIPC in 1976-1977. However, since that time there has been a low incidence of violations. Sampling and analysis techniques used for the period prior to 1978 may have caused erroneous evaluation of copper levels (Flemal, 1983). The average violation rate for the 6 stations was less than 2% from 1978 to 1985. Several violations were observed at most stations in 1985, which raises the average slightly to almost 5% for the period 1978 to 1985.

Lead concentrations in samples rarely violate the general use standard of 100 μg/1, and there is a low incidence of violations of the more restrictive 50 μg/1 water supply standard. During the period 1977 to 1981, the average violation rate was only 2.6%. There were no violations at any of the 6 stations in 1982 and 1983, and only the Montgomery and Dayton stations had violations in 1984. In 1985 there were 1 or 2 violations at each station except Algonquin. The infrequency of violations suggests that compliance with the water use standard for lead is not a major problem.

There have been occasional violations of the water use standard of 150 µg/1 for manganese. The concentration levels appear to be related to water volume and tend to decrease with decreasing flow. During the period 1982 through 1985 Dayton was the only station with violation rates in excess of 10%; all other stations had violation rates of less than 5%. Most of the manganese found in the Fox River is most likely coming from natural background sources.

Ammonia-nitrogen and un-ionized ammonia do not appear to be a problem in the basin on the basis of the samples taken at the ambient water quality stations. IEPA water quality indexes developed from the AWQMN stations indicate improvement for the period 1978-1985. However, the Hydrocomp computer simulation results indicate problems in the reach extending from south of Carpentersville to Valley View. Ammonia is highly volatile and is readily lost as ammonia gas is oxidized to nitrate. Thus its presence is discernible only in the immediate area of the discharge and may not be observed at the monitoring stations. Ammonia concentrations in effluents from treatment plants are much higher than the concentrations found in the water quality station records.

Compliance with the dissolved oxygen criterion of a minimum of 5 mg/1 appears to be fairly good in terms of the water quality station data. However, the overall average based on once-monthly samples may mask conditions during which dissolved oxygen concentrations drop below the acceptable values. Oxygen has a strong diurnal variation, with lowest values occurring at night. Samples taken at water quality stations are collected only during the day. Dissolved oxygen concentrations are also subject to seasonal fluxes. The lowest concentrations measured on the Fox River typically occur during the warmest months. The Hydrocomp computer simulation predicted violations of the dissolved oxygen standard all along the mainstem of the Fox in Kane County. The simulation showed that the severity of the problem increased in the downstream direction. In particular the simulation showed dissolved oxygen problems in several reservoir reaches during low flows.

Dissolved oxygen is one component in an interdependent cyclic system which is composed of the interactions of aquatic life, streamflow quantities, flow characteristics, nutrients, temperature, and inputs from urban and agricultural activities. Several factors which appear to exert a significant influence on dissolved oxygen concentrations in the Fox River are algal blooms, nutrient availability, and the numerous dams.

Algal blooms are abundant in the pooled reaches above the dams located along the Fox River. The viability of the algae is attributable in part to the high phosphorus levels present in the river water, which serve as a food source for the algae. Algae produce oxygen during the day and deplete oxygen at night. Supersaturated dissolved oxygen concentrations created by the algae have been measured in the pools (NIPC, 1978).

The numerous dams built in the Fox River have slowed velocities and increased depths. This reduces reaeration and subsequently lowers the assimilative capacity of the river. Further, a unique state of dissolved oxygen concentrations has been observed at the dams. Typically, the lesser depths and higher velocities occurring as water flows over a dam serve-to increase aeration and produce higher dissolved oxygen levels downstream of the dam. Along the Fox River the reverse condition has been found (NIPC, 1978). The supersaturated state of dissolved oxygen in a pool results in a release of oxygen as the water passes over the dam, and lower dissolved oxygen levels are found downstream of the dam. Problems related to low levels of dissolved oxygen may be encountered in the area downstream of a dam if the algae demand is still present.

Effluents discharged from treatment plants exert a high demand on dissolved oxygen. However, the majority of municipal treatment plants along the Fox River in Kane County have good compliance records with respect to the IEPA biological oxygen demand (BOD) standard. Exceptions are the Carpentersville main plant and the St. Charles treatment plant. Monthly effluent samples taken at the Carpentersville plant were in violation of the BOD standard 2 times in 1982, 3 times in 1983, and 7 times in 1984. Samples taken at the St. Charles plant were in violation 6, 11, and 7 times for the years 1982, 1983, and 1984, respectively. The apparent compliance with the dissolved oxygen standard at the water quality stations suggests that the main river is currently able to assimilate the waste with time. However, periodic drops in dissolved oxygen can be catastrophic to the aquatic biota and environmental integrity of the stream.

River Water for Public Supply

Given the present water quality of the Fox River, it will serve as a good source for public water supply. The City of Elgin has been using river water since 1983. Generally, the river water quality has been adequate and on a monthly basis has supplied 50 to 90% of Elgin's public water. However, during low flows, problems with odor and taste have been encountered. In order to maintain an acceptable quality of potable water, ground water is mixed with water withdrawn from the river to dilute the taste- and odor-causing compounds. During low flows (typically occurring in August), river water may supply as little as 10% of demand.

Taste- and odor-causing compounds found in the Fox River are a product of aquatic organisms such as algae. The exact source of the compounds has not been identified. The presence of the compounds has been traced from Elgin to the Fox Chain of Lakes. The City of Elgin has installed activated carbon filters to deal with the taste and odor problem. The effectiveness of the filters is still to be evaluated. Until a successful methodology is developed to deal with the taste and odor problems, a conjunctive use of ground water and surface water will be necessary.

Effects of Changes in Water Supply Sources

Changing municipal water supply sources from ground water to surface water will have a two-fold effect on downstream river flows, influencing water quality. Reducing the additive component of ground water, now discharged as effluent, will reduce river flows from levels achieved under the current supply systems. Use of river water will reduce overall flows only slightly as consumptive losses are typically not great. Water withdrawn from the river for supply will be returned via the wastewater treatment plants. The quality of the returned water will be comparable to effluents currently discharged to the river. The trend will be toward a decrease in the volume of unimpaired river water available to dilute the treatment plant discharges, and thus an overall increase in the ratio of recycled water to unimpaired river waters. The impact will be greatest in reaches where effluent outfalls are directly downstream of water intakes. In these reaches water withdrawals will result in a reduction of the river flow at the point where effluents are discharged.

Given the current degree of wastewater treatment and existing water quality conditions, it may be expected that fecal coliform bacteria concentrations will rise as effluents become a greater percentage of the flow. Localized problems with dissolved oxygen concentrations indicated by the Hydrocomp water quality modeling results (NIPC, 1978) will be magnified. Diminished instream water volume at effluent outfalls will result in higher local ammonia concentrations. The latter two conditions may remain limited to reaches immediately downstream of effluent outfalls and may not be reflected at the AWQMN stations. The 1983 IEPA facility-related stream survey (IEPA, 1984) showed that in most cases treatment plant discharges severely impacted a stream for distances less than one mile downstream of the outfall.

Rising public demand creating increases in water withdrawals and effluent returns will tend to cause a continuing decline in water quality. The impact of changes will be greatest during low flows. Low-flow statistics are examined in relation to effluent volumes in the next section.

LOW-FLOW REGIME

Low flows in the Fox River will be affected by communities switching their source of water supply from aquifers hydraulically isolated from the river to surface water or to shallow aquifers in hydraulic connection with the river. The deep sandstone aquifer is not in hydraulic connection with the Fox River, and water withdrawn from it for public use and subsequently discharged into the Fox River from water treatment plants creates an artificial increase in flows.

The present levels of effluent inflows are a significant portion of present low flows in the Fox River. Along the river in Kane County in 1984, the additive component of effluents contributed 30 to 50% of the total water flow when the flow was equal to the 1984 7-day 10-year low flow (natural flow plus 1984 effluents).

Communities that change their water supply source from the sandstone aquifer to the river will cause a relative decrease in flows by reducing the additive component. Use of water from the river will result in a reduction of flow volume because of consumptive losses. The impact of these changes on the low-flow statistics for the Fox River was investigated.

Development of Low-Flow Statistics

Data

The primary data used to develop the low-flow statistics are the historical record of daily flows measured at USGS gaging stations in the basin. Daily flow data are available for 3 gages located on the main river and 4 USGS gages located on tributaries of the Fox River in the study area. The gaging stations, drainage areas, and years of daily flow records used are shown in table 14.

The Algonquin gage is near the northern border of Kane County. The gage at Dayton is the next gage on the main river downstream of the study area. Flows at selected intermediate locations along the river in Kane County were interpolated from the gaging station data.

The Algonquin and Dayton gages have been in operation since 1916 and 1925, respectively. However, daily flow records prior to 1941 were not used because many of the existing impoundments along the Fox River were not

Table 14. USGS Gaging Stations

River/Creek	USGS gaging station no.	Location	Drainage area (sq mi)	Record used
Fox River	05552500	At Dayton, IL	2642	1941-1982
Fox River	05550000	At Algonquin, IL	1403	1941-1982
Fox River	05546500	At Wilmot, WI	868	1941-1982
Blackberry Creek	05551700	Near Yorkville, IL	70.2	1961-1982
Ferson Creek	05551200	Near St. Charles, IL	51.7	1962-1982
Poplar Creek	05550500	At Elgin, IL	35.2	1952-1982
Boone Creek	05549000	Near McHenry, IL	15.3	1949-1982

in place prior to 1940. Furthermore, no data are available for the Wilmot gage prior to 1939 when it was first placed in operation.

Methodology

There are two distinct components to the flow in the Fox River: the natural flow composed of baseflow accretions and surface runoff, and the additive component of effluents originating as ground water hydraulically isolated from the river. Increases in effluent discharges over the years have caused river flow to increase (Singh and Stall, 1973; Singh, 1983).

Low-flow statistics are affected greatly by the increase in effluent flows. Historical daily flow data collected at gaging stations must be adjusted to account for the changing artificial increases over the years. Singh and Stall (1973) investigated the impact on flow statistics of increasing effluent inflows over time. They developed a methodology for deriving 7-day 10-year low flows for streams receiving significant quantities of effluents. The 7-day 10-year low flows for northeastern Illinois, including the Fox River, were updated by Singh (1983) to 1980 effluent conditions.

The 7-day 10-year low flows for 1984, 1990, and 2000 presented in this report were derived by adding estimated increases in effluent inflows to Singh's 1980 values. Other low-flow statistics were developed by following a procedure similar to the methodology used by Singh and Stall (1973). The 31-day, 61-day, 5-month, and 9-month low flows with 10-year return period were derived for the 7 gages by subtracting effluent inflows from the daily flow data. Natural low flows at intermediate locations along the Fox River were interpolated from the gaging station values. The natural flow values were adjusted to reflect effluent conditions in 1984, 1990, and 2000. Flows were then computed on the assumption that selected cities will draw some portion of their supply from the river.

Estimation of Effluent Discharges

The IEPA began collecting effluent discharge data in the early 1970s. Effluent loads for the period prior to that date may be estimated from water use information. Water use as measured by meters installed on the inflow lines from the supplier represents the quantity of water pumped from the wells. Therefore the average daily pumpage or use throughout the year, in million gallons per day (mgd), refers to total water withdrawals from the supply system. Actual water use computed from billing records is typically less. The difference is attributed to unmetered uses such as fire fighting and public use in parks or fountains, and system loss. This water is not returned to waste treatment facilities. The percent of total water withdrawn which is unaccounted for varies from city to city. Differences of 10 to 15% between withdrawals and metered use are considered acceptable (Howe, 1971; Keller, 1976). Differences between withdrawals and returns (wastewater inflows) tend to be greatest during dry periods when system losses and consumptive use are greatest.

Numerous self-supplied industries in the study area discharge their wastewater through city systems, and from time to time industries have operated private treatment plants. Historical records for industrial effluent discharges and well-water withdrawals are sketchy. Industrial contributions to effluents discharged to the Fox River were estimated from data and reports from studies of water use (Sasman et al., 1974, 1982; Sasman, 1965; Kirk et al., 1979, 1982, 1984, 1985).

Effluent discharges to the Fox River for the period 1940 to 1983 were estimated from the municipal and industrial water use data adjusted for seasonal losses. These values were compared to available waste treatment plant discharge data obtained through the cooperation of the IEPA.

Comparison of reported water withdrawals to IEPA records of effluent discharges for Elgin and Aurora show that the lowest monthly average for effluent outflows exceeded the average annual withdrawals. Several factors may be contributing to this apparent water gain. Residents and industries utilizing the sanitary sewers may be obtaining water from private wells for which withdrawals have not been reported. Both cities have some combined storm and sanitary sewers, which may result in stormwater passing through the treatment plant, although typically during dry periods this would be minimal. Seepage problems from springs in the Aurora area have been identified. Lower treatment plant flows have been observed since a program of sewer repair and replacement was initiated in Aurora.

Because of the interconnection of the water supply systems for Batavia, Geneva, and St. Charles, water withdrawals for each city are not directly comparable to individual treatment plant outflows. The combined water withdrawals are consistent with the combined effluent discharges.

Low-Flow Statistics for Present and Projected Conditions

Low-flow statistics were developed for effluent conditions in 1984 and estimated effluent inflows in 1990 and 2000 for 14 locations along the Fox River. These 14 locations are shown on the map in Figure 4 and the schematic sketch in Figure 5. The locations marked with a solid circle in Figure 4 correspond to the numbered circles in Figure 5. Most of the 14 sites are situated upstream of wastewater treatment plant outfalls.

A sufficient quantity of water must be available in the river to dilute the treatment plant effluents and for the river to assimilate the waste loads without extreme degradation of the river ecology and water quality. The 7-day 10-year low flow is the flow parameter currently used by the Illinois Environmental Protection Agency to evaluate the volume of effluents which may be discharged into a receiving stream.

Table 15 lists the 7-day 10-year low-flow values calculated for each of the 14 sites for effluent conditions in 1984, 1990, and 2000. It is assumed that no water withdrawals are made when flows are equal to or less than the 7-day 10-year low flow; thus the values reflect natural flows plus accumulated effluent inflows. The estimate of 7-day 10-year low flow increases with time at each site as effluent volumes increase with population growth.

The 7-day 10-year low flow serves as a datum from which the relative assimilative capacity of the river is judged. Currently the IEPA requires that the effluent outflow from treatment plants not exceed a 1 to 5 dilution ratio with the 7-day 10-year low flow of the receiving stream.

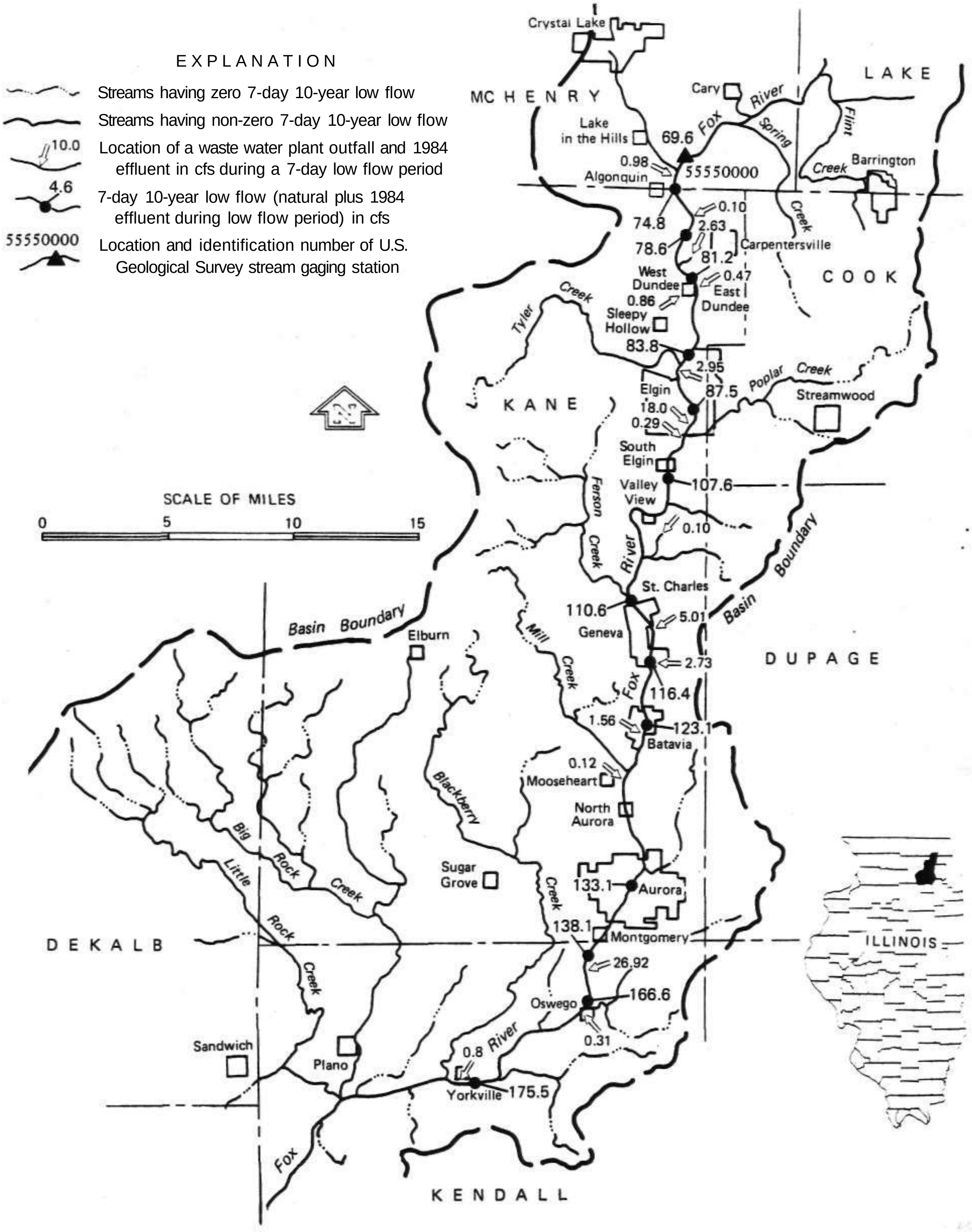

Figure 4. 7-day 10-year low flows

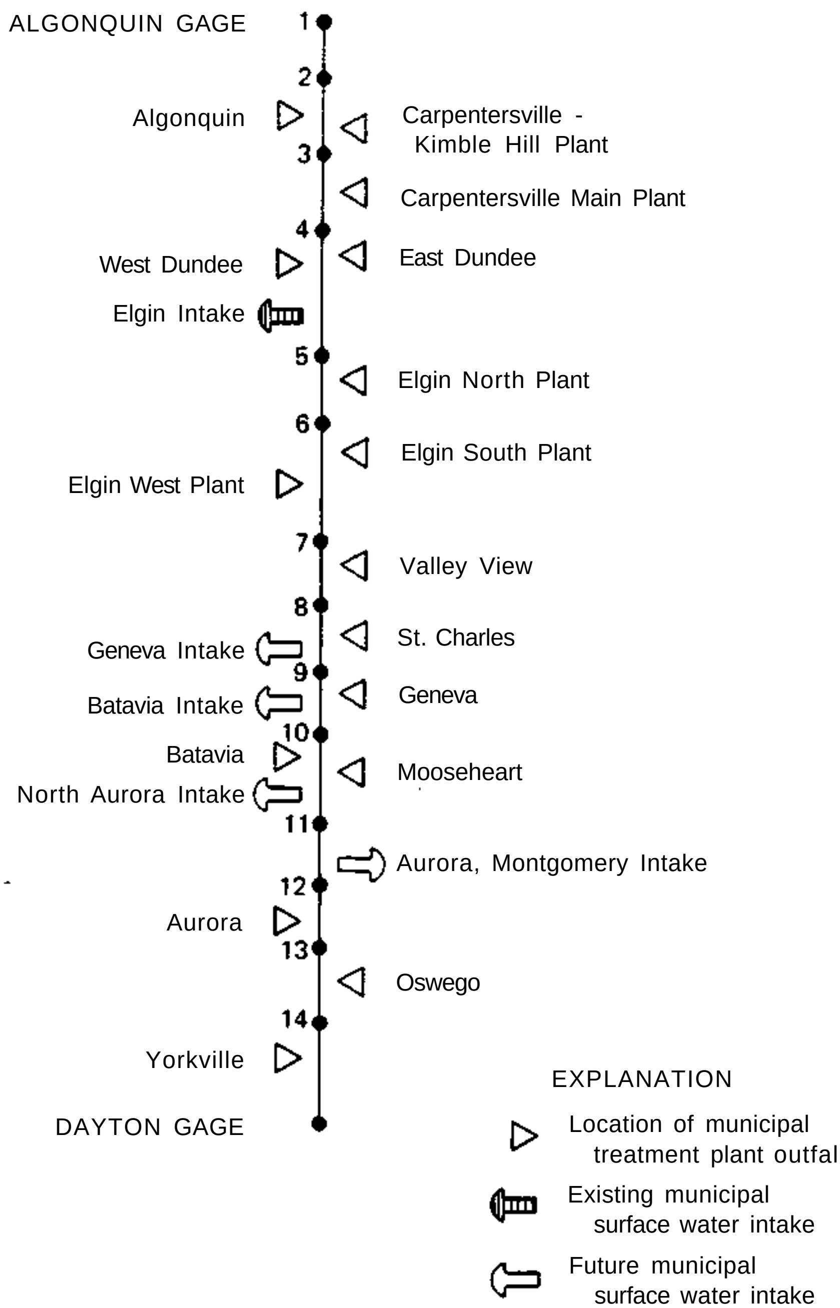

Figure 5. Schematic of Fox River, wastewater treatment plant outfalls, and existing and future municipal surface water intakes

Table 15. 7-day 10-year Low Flows

Site	Present conditions 1984	Projected (no withdrawals from Fox River) 1990	2000
1	69.64	75.17	85.32
2	74.81	80.72	92.51
3	78.60	84.64	96.95
4	81.24	87.23	99.95
5	83.84	89.98	102.86
6	87.51	94.04	107.36
7	107.69	116.63	132.65
8	110.64	119.65	135.68
9	116.35	125.17	142.82
10	123.08	132.61	149.93
11	133.14	142.84	160.42
12	138.14	147.84	165.42
13	166.56	178.78	199.28
14	175.46	187.74	208.32

Typically the treatment plant flow that is compared is the lowest average flow during a 7-day period. This low-flow period for the treatment plant generally coincides with dry periods and low river flow. During dry weather combined sewer overflows and ground-water seepage are minimal, and the discharge from the plant more closely reflects the actual effluent load.

The assimilative capacity of the river at a particular location is affected by the upstream waste loads. As effluents become a greater percentage of the river flow, the overall water quality may diminish. Evaluation of the assimilative capacity of the Fox River is beyond the scope of this investigation. The effects of changing sources of water supply (from ground water to river water) on low-flow statistics will be discussed in terms of flow volumes relative to the 7-day 10-year low flows (adjusted for effluent inflows).

Assuming there are no water withdrawals from the river, estimated 1984 7-day 10-year effluent flow from the Elgin south plant is approximately one-fifth of the river's 7-day 10-year low flow (adjusted to 1984 conditions). Aurora's treatment plant flow is approximately one-fifth of the 7-day 10-year low flow for the river at that location. On the basis of 1984, 1990, and 2000 conditions, any water withdrawal above Elgin's south plant during a flow equal to the 7-day 10-year low flow would result in effluents exceeding one-fifth of the river flow. Projected demand and estimated effluent conditions show that by 1990 any water withdrawals reducing the river flow above Aurora's treatment plant will likewise result in effluent volume exceeding one-fifth of the river flow volume during a discharge equal to the 7-day 10-year low flow. It is therefore assumed that no water withdrawals may be made during the 7-day 10-year low flow.

Aurora, Batavia, Geneva, and St. Charles water supply systems currently derive all or most of their water from the sandstone aquifer. Low-flow statistics were developed given that these four systems join Elgin in converting to conjunctive use of river water and ground water. The schematic in Figure 5 shows the location of potential water supply withdrawals for the 5 systems relative to the 14 sites for which low-flow statistics were calculated. Water withdrawals are subtracted from flows upstream of the cities' effluent outfalls.

The 31-day, 61-day, 5-month, and 9-month low flows with 10-year return periods were calculated for each of the 14 sites. The natural flow values were adjusted for 1984, 1990, and 2000 effluent inflows. Two scenarios of water withdrawals were investigated. The 31-day 10-year and 61-day 10-year low flows were adjusted at each of the 14 sites given that the 5 supply systems each withdraw at the rate of 25% of their average annual demand during the low-flow period. The 31-day, 61-day, 5-month, and 9-month 10-year low flows were calculated given that these five supply systems withdraw at the rate of 75% of their average annual demand during the low-flow period.

On the basis of withdrawal rates of 25% of average annual demand, the adjusted values for the 31-day 10-year and 61-day 10-year low flows at each location and each year are greater than the 7-day 10-year low flow. Thus, there would be adequate river water to supply approximately 25% of the demand, averaged over a 31- or 61-day low-flow period, although there may be some days when no withdrawals may be made.

Withdrawals of 75% of the average annual demand have a more significant effect on the low-flow statistics. When no water withdrawals are made, the estimated 31-day 10-year low flows between Elgin and St. Charles are typically 20 to 25% greater than the corresponding 7-day 10-year low flow. Given that river water is used to supply 75% of demand, the 31-day 10-year low flow is reduced to only about 10% more than the 7-day 10-year low flow for this reach. Between St. Charles and Aurora the 31-day 10-year low flow would exceed the 7-day 10-year low flow by less than 10% until about 1990, and by 2000 the 31-day 10-year low flow would be approximately equal to the 7-day 10-year low flow. Downstream of Aurora to Yorkville, the 31-day 10-year low-flow values are below the comparable 7-day 10-year low-flow values for each year. By the year 2000 a supply rate of 75% of average annual demand would reduce the 61-day 10-year low flow between Aurora and Yorkville to approximately the comparable 7-day 10-year low-flow value. These comparisons are based on the 7-day 10-year low flows in Table 15, which represent natural flows plus effluents with no water withdrawals.

The above-noted statistics imply that there is a 1 in 10 chance each year that one 31-day average flow in the river would be so low that withdrawal averaging the 75% demand rate would reduce flows to the 7-day 10-year low flow or less between Elgin and Yorkville. Similarly, there is a 1 in 10 chance that for 61 days, on the average, flows downstream of Aurora would be reduced to 7-day 10-year low-flow levels or less if withdrawals continued at the 75% rate.

Sustained extreme low flows would stress the stream aquatic life. Furthermore, accumulated effluent volume, particularly as it increases with time, would become a significant percentage of the flow for longer periods of time. Given the inferior quality of effluents compared to the natural flow, this would further increase adverse impacts on the stream ecology and water quality. High coliform bacteria counts, noted earlier in this report, would be expected to continue and increase. Problems with high ammonia concentrations downstream of effluent outfalls would be aggravated.

The 5-month and 9-month 10-year low-flow values computed for the 14 sites indicated that there is more than ample flow during these droughts to provide for withdrawal rates which average 75% of the annual demand rate. The projected demand is only a small fraction of the average flows for these sustained low flows. More severe droughts with long return periods were not evaluated.

While the water supply needs for the five supply systems are small compared to typical daily flows in the Fox River, it is important to note that accumulated effluent inflows from all treatment plants are significant compared to low flows. The 7-day 10-year low-flow values computed for projected effluent loads in 1990 and 2000 typically account for about one-half of the flow listed in Table 15. Below Aurora's effluent outfall, the sum of all effluents discharged into the Fox River is estimated to be approximately 88 cfs in 1984, 100 cfs in 1990, and 121 cfs in 2000 compared to the estimated natural 7-day 10-year low flow of 87 cfs at Yorkville. Based on the two water withdrawal scenarios presented, accumulated effluent inflows account for 25% or more of the estimated 31-day 10-year and 61-day 10-year low flows. The water quality data suggest that the natural cleansing mechanisms of the river are sufficient to maintain water quality under existing conditions. However, sustained periods of exceptionally low flow created by river water withdrawals (and subsequent reduction in the additive component of ground water), coupled with increasing effluent loads, may lead to low-flow water quality problems in the future.

SUMMARY

1. The water budgets developed from the field data indicate that the present levels of pumpage from wells near the river may already be reducing discharges from aquifers to the river. It is probable that additional water withdrawals from existing or new wells open to shallow aquifers near the river would further diminish baseflow accretions along the river.
2. Present river water quality is very good. Problems with taste- and odor-causing compounds during low flows will probably necessitate conjunctive use of ground water and surface water during low flows.
3. The river appears to have sufficient assimilative capacity to handle present conditions of effluent loads. A reduction in low flows or an extended duration of low flows (due to water withdrawals) may escalate current local and/or minor water quality problems.
4. The volume of effluent loads precludes withdrawal of river water during flows less than or equal to the 7-day 10-year low flow for present and future conditions.
5. Average river flows appear to be sufficient to supply all the demand currently met from the Cambrian-Ordovician aquifer for the five water supply systems considered. River water withdrawals may be limited during low flows in the range of 31-day 10-year or 61-day 10-year low flows in order to meet effluent dilution standards and avoid possible adverse impacts to the stream ecology arising from artificially extended durations of extreme low flows.
6. For drought periods with flows of the order of the 5-month and 9-month 10-year low flows, no limitations on water withdrawals are necessary.
7. Effluents currently form a significant percent of the volume of low river flow. Use of river water for water supply and subsequent discharge of wastewater to the river will result in an increasing ratio of wastewater to unimpaired (unused) water in the river.
8. The effect of communities switching to the river or to shallow aquifers hydraulically connected with the river will be to lessen anticipated future low flows due to the elimination of the ground-water additive component. Use of river water for public supply and for dilution of wastewater may lead to conflicting needs in the future.

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